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A proposed methodology for determining operational hit probabilities for M-60 tanks

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A PROPOSED METHODOLOGY FOR DETERMINING OPERATIONAL HIT PROBABILITIES FOR M-60 TANKS

by

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ABSTRACT

The Department of the Army has requested the U.S. Combat Developments Command develop a methodology for determining operational hit probabilities for three pilot man-weapons systems, one of which is the M-60 tank, where the operating personnel are subjected to the psychological and physiological stresses of the simulated combat environment. This thesis describes a proposed experimental methodology applicable to the time frame FY 1969 and beyond for obtaining hit probabilities to include the preliminary experimental unit firing exercises and method of selection, the courses to be fired, the instrumentation requirements, several statistical techniques to be used in data reduction, a format for presenting the resulting data and the costs involved in the experiment. The environment is non-toxic.

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1. Introduction

What is the expected operational (combat) hit probability for a 105 mm, M-60 tank cannon fired in an attack against an aggressor medium tank dug in at a range of 1500 meters somewhere on the plains of Central Europe on a clear winter day?

The hypothetical question posed is typical of those posed in the US Army since the early 1960's when concern developed in the Department of Defense over comparison of weapons systems to determine how the DOD budget should be spent to get the most utility (effectiveness) for the dollars spent on weapons systems. The heart of this problem is the effectiveness of the man-weapon system, that is, what is the target effect per round, shot, burst, etc. Although it is recognized that target hits, as well as the subsequent terminal effects, will be determined by the laws of probability; Army agencies have not yet conducted sufficient study and experimentation to estimate the appropriate parameters so that operational predictions can be made. Even the basic weapon, the rifle, the principal arm of the "Queen of Battle" in the US Army, has only recently been effectively measured on a simulated battlefield where firers were stressed with live fire against pop-up targets and real time decisions as to which targets to engage. With the rapid evolution of the applications of operations research and systems analysis to the solution of the problem of just how operationally effective is any particular man-weapon system, the Army, as well as the sister services, has undertaken the development of experimental methodology to measure system effectiveness.

In 1965, the Department of the Army directed the Combat Developments Command, which is responsible for how the Army will be organized, how it will be equipped and how it will fight, to conduct a study to develop the methodology by which information on operational hit probabilities for all Army systems could be obtained. (OHP refers to the probability that a crew, or single firer, under the stress of combat conditions will hit a particular target, which should logically be combined with conditional kill given hit data to yield unconditional probability of kill.) The resultant information would be invaluable for use by operations researchers, system analysts, war gamers and military planners. In 1965 only nuclear weapons had been satisfactorily tabled to permit researchers and planners to make comparative analyses of effectiveness. Department of the Army specified that it would review CDC's study results to determine if the development of OHP should become an ongoing program to develop OHP for all Army weapons systems except long range missiles.

Recognizing that a change in any one of the eight typical variables in our hypothetical question meant a new question was asked, CDC considered the magnitude of the solution to the OHP problem. For example, in tank systems, allowing for a minimum of three types of US tanks with two types of main gun ammo, four tactical postures for US and aggressor weapons systems, four principal ranges, five typical aggressor target complexes to include moving tank targets, five types of terrain, three visibility conditions and three temperature levels, there are 21,600 combinations to be considered. Each combination would require the firing of at least 30 rounds of main gun ammo (see Appendix A) at an approximate cost of $80 (if the opportunity cost is considered equal to the cost of a new round) for a total of nearly $52 million in ammo cost just to observe first round hits. This figure does not include the cost of pay and travel and per diem allowances for the experimenters and test subjects, vehicle transportation, operation and maintenance costs, cost of constructing and maintaining the instrumented targets, and the cost of analyzing the test data and publication of the results. And this only for tank systems; there were many more systems besides the tank which could be considered in the study. The immediate conclusion drawn was that large costs were involved and the question that followed was what methodology should be used to determine weapon system OHP satisfactorily at a cost the Army could afford. The words satisfactorily and afford are very elusive; however, both will be amplified in the material which follows.

At this point in time the Army's budget included no obligational authority for the OHP program. Past experimentation had looked into only a few of the individual components of OHP, and, therefore, could only serve as a partial guide to point the way for future experimentation. The big question still remained, "Could a methodology be developed to obtain weapons systems OHP at a cost the Army could afford?" The scarce resource is money. CDC in coordination with the Army Material Command and the Continental Army Command, responsible for the Army's hardware and troop training respectively, met and agreed that a reduced pilot program should be carried out first to permit the decision maker at DA level to determine if the OHP data that could be obtained was worth the cost and thereby determine if the program should be continued by examining all weapons systems except long range missiles. The pilot program outlined would address a typical tank, infantry and artillery weapon system which would serve to reduce the scope of the initial study. With this accomplished CDC forwarded the mission to its experimental command, CDCEC, to conduct the pilot program with the 105 mm gun tank, the 155 mm self propelled howitzer and the hand held grenade launcher. CDCEC was tasked to develop the methodology for determining OHP for each weapons system and to identify problem areas, which implies identification of costs involved.[1] The use of "on the shelf" valid data from arsenals, the Ballistics Research Laboratories and from previous field experiments such as those run by O.R.O. (later R.A.C.) and the Human Engineering Laboratories was encouraged to avoid costly duplication. Likewise combat data could contribute to the study.

Although CDC had reduced the scope of the problem considerably by restricting the initial study to only three weapons systems, there were still many unknowns and only

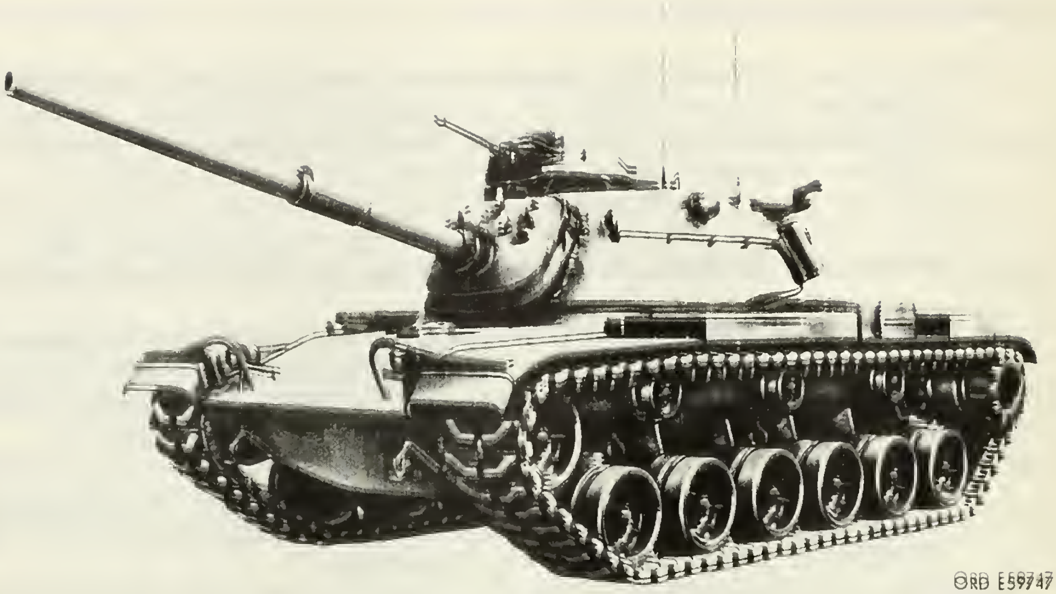
[1] Conference on Preparation of a Coordinated... Selected US Army Weapons Systems (Memorandum for Record. Ft. Belvoir: USACDC, 27 March 1964), pp 1-7.

locally available funds with which to defray costs. CDCEC formed a pilot study team to which it gave the following mission in five parts.

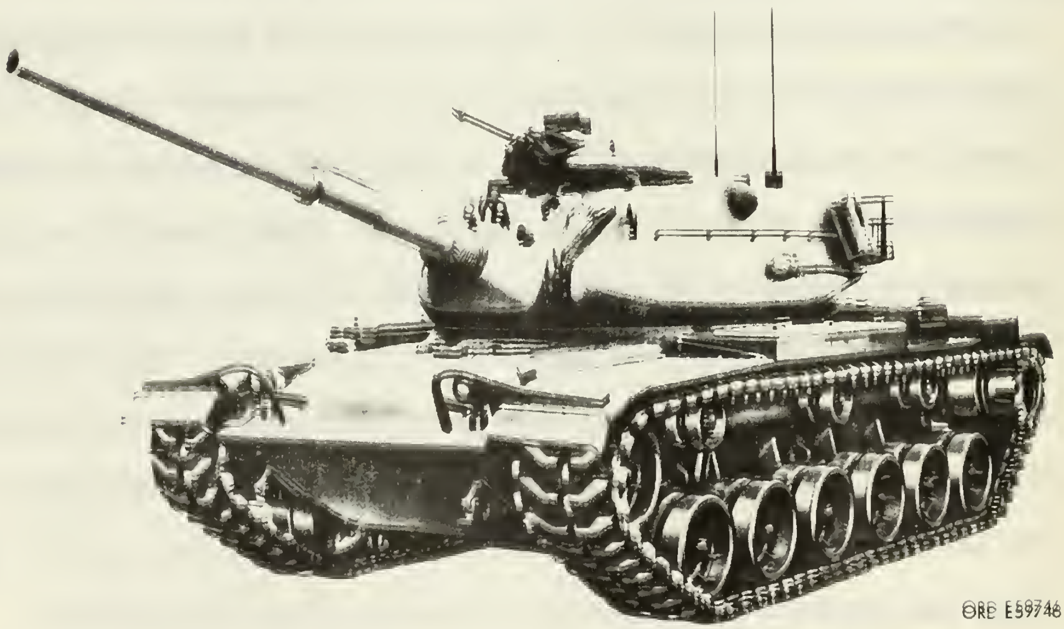
> a. "Develop procedures, techniques and methodologies to be utilized in data collection, reduction and correlation to obtain standardized tactical effectiveness data on weapons to be examined."
>
> b. "Develop the format for portraying the tactical effectiveness data of weapons examined."
>
> c. "Determine the psychological and physiological environments influencing hit probabilities and develop objective meaningful measurements of variables and effective control of constants."
>
> d. "Determine, for project analysis purposes, data requirements for appropriate experiments in the USACDCEC Experimentation Program."
>
> e. "Determine the feasibility of a follow-on program."[1]

In the accomplishment of its mission the pilot study team must research past experimental work in order to gain insight into the development of methodology and problems involved in conducting a reduced scale pilot OHP study for three specific weapons systems. It must also publish data requirements to the experimentation teams which will conduct field experiments with the specified weapons. Because of the limited funds available for the study, the pilot program cannot be an exhaustive study of all situations, terrain, etc., but, must be conducted in sufficient detail to provide the decision maker with the necessary information upon which to base his decision of whether to request obligational

[1]Clarification of TEWS Study Group Memorandum of Instructions (Memorandum for Record. Ft. Ord: USACDCEC, 31 October 1966), p. 1.



105-MM GUN, FULL TRACKED, COMBAT TANK M60 - LEFT FLANK VIEW.



105-MM GUN, FULL TRACKED, COMBAT TANK M60A1 - LEFT FLANK VIEW.

FIGURE 1

authority to initiate a full blown program, continue the pilot program with locally available funds or stop the operation.

Thus the stage is set for the specific approach to be taken in this thesis which will be to restrict attention to the 105 mm gun tank system and to consider only the development of parts "a-c" of the pilot study mission with emphasis on developing an experimental methodology. The proposed methodology will address all three weapons sub-systems on the M-60 tank, the 105 mm main gun, the coaxial 7.62 mm machine gun and the caliber .50 machine gun in the non-toxic environment. The employment of all weapons sub-systems during a tactical engagement is felt to be essential to realism and the maintenance of the stress factor on the crew.

The time frame to which the proposed methodology is applicable is FY 1969 and beyond, when reliable, sophisticated instrumentaion systems, to include a high speed, large memory capacity digital computer capable of real time decisions as well as data recording, and a direct fire hit and miss location sensor are predicted could be available in addition to the instrumentation systems already proven reliable, all of which are considered necessary to evaluate a group of tank systems operating over relatively extended distances. The views and opinions expressed are those of the author and do not necessarily reflect the official position of the Combat Developments Command Experimental Command.

The problem will be addressed in three major parts. First, a look will be taken at what research agencies have accomplished in the past to adopt all procedures, techniques and facts which are usable. Second, a methodology will be described for the conduct of field experimentation to fill in gaps not covered by past experiments. Finally the applicable cost will be described. Throughout the criterion is to minimize cost subject to a satisfactory level of experimentation and data gathering effectiveness.

In that the pilot program need not examine every firing combination in order to be used as a decision model, there are several methods which may be employed to reduce the cost of the M-60 tank portion of the pilot program without reducing the validity of the results.

(a) In the 105 mm gun tank pilot experimental program fire only two types of main gun ammo, the high explosive antitank practice round (HEAT-TP) and the high explosive plastic round (HEP-T). (If ammo allowances and the instrumentation capability permit, the armor piercing (APDS-T) round could be included and HEAT-T could be used rather than HEAT-TP.)

(b) Use pooled equipment at one test site and address only one type of terrain.

(c) Consider only three aggressor tank complexes (1) tanks and armored carriers of near tank size, both moving and stationary, (2) antitank guns and (3) rocket launcher teams, automatic weapons teams and troops. The tanks and armored carriers would be engaged by main guns only, the antitank guns would be engaged with any gun with the range capability and rocket launcher teams, automatic weapons teams and the troops would be engaged with the machine guns.

(d) Assume temperature to be of secondary importance.

These methods reduce the variables, and hence costs, to four tactical situations (attack, defense, delay and meeting engagement), four principal ranges (600, 1100, 1500 and 1900 meters for the main gun; 600, 1100 and 1500 meters for the caliber .50 machine gun and 600 meters and below for the 7.62 mm machine gun), three types of target complexes as just described, and three visibility conditions (day, clear; night, clear and reduced visibility such as dawn, dusk or haze). In the day defense and day delay it may be desirable to add a longer range for the main gun. The variables are considered the minimum desired; however, each combination may be ranked so that if budgetary limitations impose further reductions, the test director would readily know which combinations have priority.

The following priority matrix is recommended based on the list of variables just described.

TABLE I

ORDER OF PRIORITY FOR EXPERIMENTATION

	Tactical Situation	Weapon	Range	Target	Visibility
1.	Attack and defense	105 mm	All	All applicable	Day and night
2.	Attack and defense	7.62 mm and cal. .50	600 and below 600, 1100, 1500	All applicable	Day and night
3.	Delay	All	All	All	Day and night
4.	Attack and defense	105 mm	All	All applicable	Reduced visibility
5.	Attack and defense	7.62 mm and cal. .50	600 and below 600, 1100, 1500	All applicable	Reduced visibility
6.	Meeting engagement	All	All	All	Day and night
7.	Meeting engagement	All	All	All	Reduced visibility

Because costs are large and may exceed whatever budget is allocated, it behooves us to look for other ways to reduce the total cost without falling below the desired level of experimental effectiveness. If priorities 1 through 6 or at least 1 through 3 are executed an additional saving may be possible during the experiment if statistical tests show that for the same set of variables for the attack and meeting engagement and the defense and the delay, the hypothesis may be accepted that the estimated hit probabilities are respectively the same. Intuitively one would expect the two variations of the offense and the two variations of the defense to be quite similar. The statistical test to be performed is outlined in Appendix B and the appropriate time for its use and the expected saving will be discussed in a later section when the detailed experiment is developed.

2. Past Experiments Guide the Future

There have been two past experiments which input significantly into the development of the methodology for determining tank system OHP. In 1955 PROJECT STALK studied the time required for an individual tank crew to engage surprise targets. Since this experiment was conducted before the use of instrumented target systems, much of the measurement had to be accomplished by personnel (recorders) mounted in seats fastened to the rear of the tank turret, using Esterline-Angus pen recorders to record the time at which target detection, identification, and engagement took place.[1]

In 1956-57, PROJECT ARNO, ARNO stands for armor night operations, compared the ability of a tank platoon to engage simulated targets during day and night attack.[2]

From these experiments the researcher may conclude that considerable useful data for the M-48 series medium tank, one of the two medium tanks in the current inventory, was collected under conditions approximating those found on the battlefield; however, no experimental data was obtained on the 105 mm gun tank, our test subject. Experimental methodology for obtaining operational hit probabilities and time to fire distributions were developed in both experiments. Some improvements are now possible due to technological

[1]D.C. Hardison, et al., A Partial Analysis of Project STALK Data with Results of Single Tank Versus Single Tank Duels (BRL Tech Note 980, February 1955), pp. 6-14.

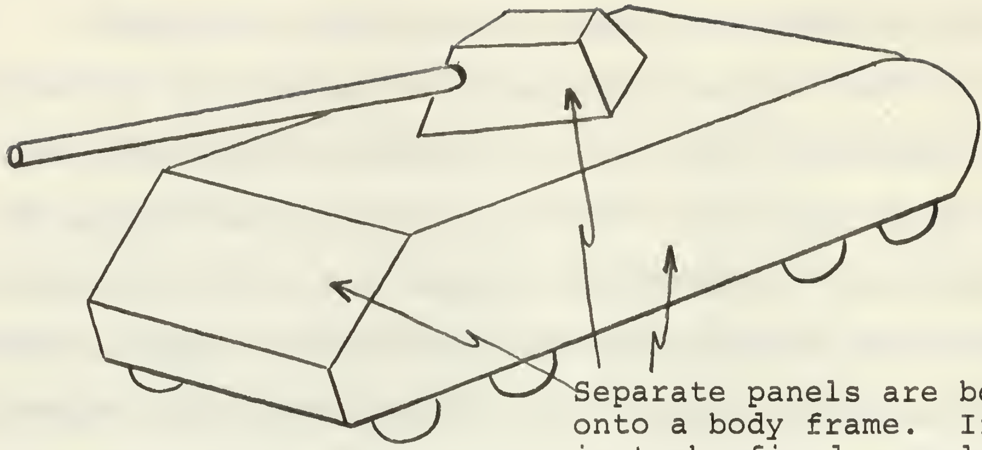
[2]J.A. Bruner, et al., Project ARNO Night and Day Tactical Fire Effectiveness of Tank Units (U) (ORO-T-371, May 1958), pp. 1-3.

advances in instrumentation which can and should be included in this experiment and they are described as follows.

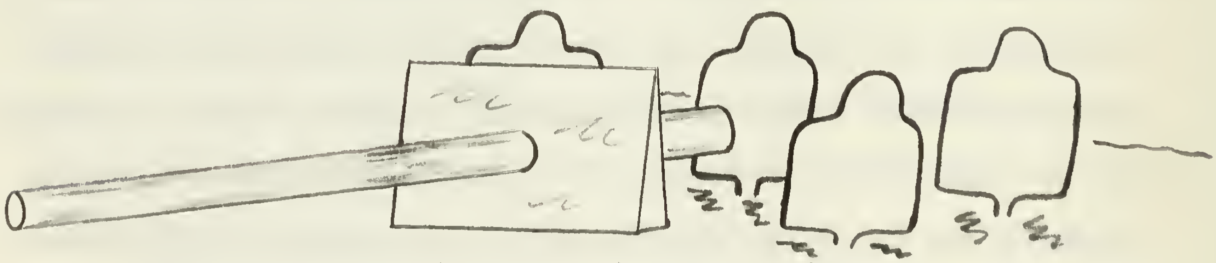
(a) Although the heart of the problem is the OHP of an individual tank, this OHP cannot be accurately determined out of context. That is, it must be measured as in ARNO under the stress of the command and control problem of directing and distributing the fires of all tanks in a unit against multiple targets. Only through empirical observation of platoons or companies can predictions be made about platoons or companies. ARNO disclosed weaknesses in the state of training with respect to proper fire distribution which should be further examined in the study of OHP.

Therefore in the pilot program we want to observe not only the hit probability for each armor defeating round fired and area effects for all other rounds, but also the degree of underkill or overkill. In keeping with the experimental criterion, the platoon is the minimum size which provides an appropriate level of command and control stress; however, in any follow on program, consideration should be given to raising the level to reinforced company level to more fully evaluate the effect of massed armor firepower employing fire and maneuver by platoon.

(b) Targets should be 3D whenever feasible to provide realistic targets for detection and identification and should be capable of being electronically controlled. The instrumentation on the armored targets should be capable of sensing with reasonable precision and recording with the computer when and where the targets have been hit and when



A proposed tank target to supplement the Bisset-Berman reduced scale tank target currently available. The engine is mounted in extreme rear and as low as possible. Whenever possible, the chassis would be put in some defilade to protect drive mechanism. With the turret removed this would be an armored personnel carrier.



Proposed antitank target incorporating currently available pop-up target sensing system with the sensing silhouette replaced with "F" type cardboard target, which falls down when hit and sends this sensing to the computer.

This same system less the AT gun is proposed for troop, rocket launcher team and automatic weapons team targets.

PROPOSED TARGET SYSTEMS
Figure 2

and where the round passed in relation to the target if it missed. After each run, it is recommended that the hits be personally checked to ensure only main gun rounds were scored as hits. The 3D tank targets envisioned would look like the ones depicted in figure 2. There are tank targets, called Bisset-Berman target tanks, which are currently available and have all the desired characteristics except a sensing device to record accurately the time and location of hits and misses. With the appropriate modification to mount a sensor system, the Bisset-Berman is a satisfactory tank target. Previous experiments recorded the first hit as a kill, whereas, this was not necessarily true. Since then, computer programs have been developed which now allow the computer to determine quickly, from inputs from hit recording devices and by applying Monte Carlo techniques, if a hit should be credited as no significant damage, a firepower kill, mobility kill or total kill. Having made a determination, the computer can update instructions to the target so it will respond realistically. Thus if a tank crew fires and achieves a hit but fails to relay and fire again when the target is still threat, we can note this fact. A damaged tank is like a wounded elephant; it must be assumed to be dangerous until proven otherwise.

The personnel targets or weapons targets manned by personnel would be engaged by tank weapons which achieve area effect. Each personnel target should be capable of falling down when it is hit by either a machine gun bullet or by a fragment from a high explosive round and should be capable of sensing through its "halo effect" when near misses are occurring. The "halo" in effect senses suppressive fire.

(c) Several tactical postures must be considered, i.e., the attack, defense, delay and meeting engagement are all important. So far only the attack, day and night, have been explored in ARNO.

(d) Although statistical control must be exercised in order to obtain meaningful results, control must allow real time exercises and as much movement as possible to be used to stress the tank crews and hence tend to simulate the battlefield realistically. It should be noted, tank cannon are inherently accurate because of their long gun tubes and carefully manufactured ammunition. Tank cannon laid under optimum conditions are capable of striking a target in excess of 80% of the time located at 1500 meters distance. As a matter of fact the bulk of the rounds will strike within 24 inches of the aiming point. Yet field experience has shown every tank leader that his crews seldom equal or exceed the limit of the system when movement and real time stresses are applied such as in ARNO or the tank crew gunnery qualification table (a moving, real time exercise fired day and night against both moving and stationary targets) due largely to aiming errors.

The statistical control limitations on movement during the time of the <u>firing engagement</u> would be to require the platoon to limit its maneuver to selection and occupation of primary and alternate firing positions. Thus all tanks would be firing from approximately the same sample range bracket, which we shall specify to be 100 meters plus or minus measured from the basic range sampling points. The target control program would obtain the range between the tank platoon and the targets through the direct range measuring system and would present targets soon after the range fell within a prescribed bracket. For example, let us say the next set of targets in an attack exercise are to be engaged at 1600 - 1400 meters (the 1500 meter bracket). Soon after the platoon enters the bracket the computer would cause the targets to appear and fire on the attacking US platoon. The platoon engages the targets with fire and limited maneuver. The result is felt to be a workable compromise between tactical realism and statistical control. In the offense as the US platoon moves to the objective, targets will appear randomly to the right and left and at near and far ranges so that the platoon may engage its initial set of targets at the 1500 meter bracket, fire at several more target sets at different ranges and later fire another exercise at the 1500 meter bracket. In the defense we would exercise the same sort of fire engagement control. We will comment more on this control when we discuss the defense in detail.

(e) Although ARNO considered night operations, periods of reduced visibility such as dawn, dusk or periods of similar dim light intensity have not been explored. Because these periods have been historically used by armed forces the world over, they deserve attention also.

These deficiencies will be corrected in the proposed methodology to follow. By using more sophisticated instrumentation we hope to get more valid results in a form that lends itself to more rapid data processing.

3. What Must be Measured

In a tank firing experiment there are three vital points to be measured for the experimental unit, the tank, employed in its normal platoon role. The first is accuracy, i.e., for a specific type of main gun ammo, light condition, range, state of target movement, the sequence number of the round and tactical situation what is the mean and standard deviation of the aiming point in the Y-Z plane. (In using the standard 3 coordinate system, we mean that Y and Z describe the plane perpendicular to the axis of fire, the X axis.) After the main gun is boresighted and zeroed according to accepted doctrine for the wind and temperature conditions applicable to a test phase, the expected strike of the round is the aiming point. The distribution of aiming error is predicted to be influenced by the six basic factors just mentioned, plus a number of other less significant parameters which will be lumped into the error term. Four of the factors are included as arguments of a function to indicate there is some reason to believe there may be interaction between two or more of the factors. The attack and meeting engagement are described in the first model and the defense and delay are described in the second. The error terms are assumed to be $N(0,\sigma_{ij}^2)$, $i = 1$ (attack or meeting engagement) or 2 (defense or delay) and $j = 1$ (Y), or 2 (Z).

The attack and meeting engagement model is,

$$Y_{ijklmno} = \mu_Y + Ts_i + A_j + f(Tm_k, Ra_\ell, V_m, Ro_n) + e^Y_{ijklmno}$$

$$Z_{ijklmno} = \mu_Z + Ts_i + A_j + f(Tm_k, Ra_\ell, V_m, Ro_n) + e^Z_{ijklmno}$$

The defense and delay model is,

$$Y_{ijklmno} = \overset{*}{\mu}_Y + Ts_i + \overset{*}{A}_j + f(\overset{*}{Tm}_k, \overset{*}{Ra}_\ell, \overset{*}{V}_m, \overset{*}{Ro}_n) + e^{*Y}_{ijklmno}$$

$$Z_{ijklmno} = \overset{*}{\mu}_Z + Ts_i + \overset{*}{A}_j + f(\overset{*}{Tm}_k, \overset{*}{Ra}_\ell, \overset{*}{V}_m, \overset{*}{Ro}_n) + e^{*Z}_{ijklmno}$$

with the following definitions,

u_Y is the average y component of aiming error (attack or meeting engagement) before the operational conditions are applied.

u_Z is the average z component of aiming error (attack or meeting engagement) before the operational conditions are applied.

Ts_i $i = 1,2,3,4$, is the effect in the y or z direction due to the tactical situation.

A_j $j = 1,2,....$, is the effect in the y or z direction due to the type of round fired in the attack or the meeting engagement. The upper limit is not fixed to permit the inclusion of more rounds if desired.

Tm_k $k = 1,2$, is the effect in the y or z direction due to whether the target is moving or stationary in an attack or meeting engagement situation.

Ra_ℓ $\ell = 1,2,3,4$, is the effect in the y or z direction due to the ℓth range bracket in an attack or meeting engagement situation.

V_m $m = 1,2,3,4,5,6,7$, is the effect in the y or z direction due to the visibility in an attack or meeting engagement. (The seven conditions are day, and night, dawn and dusk w/white light or w/infrared.)

Ro_n — $n = 1,2,3$, is the effect in the y or z direction due to sequence number of the round where we differentiate between first, second and other rounds fired in the attack or meeting engagement.

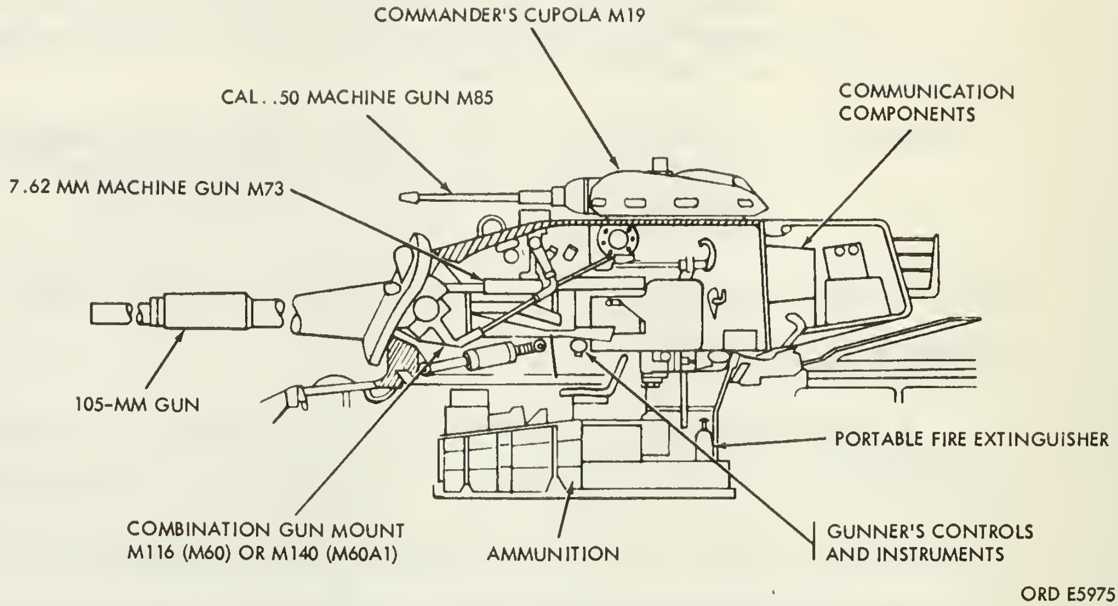
o — $o = 1,2,3,\ldots,t$, is the oth round fired by any one of the tanks in the platoon as a group with the same i through nth coordinate.

The starred parameters for the defense and the delay are defined similarly.

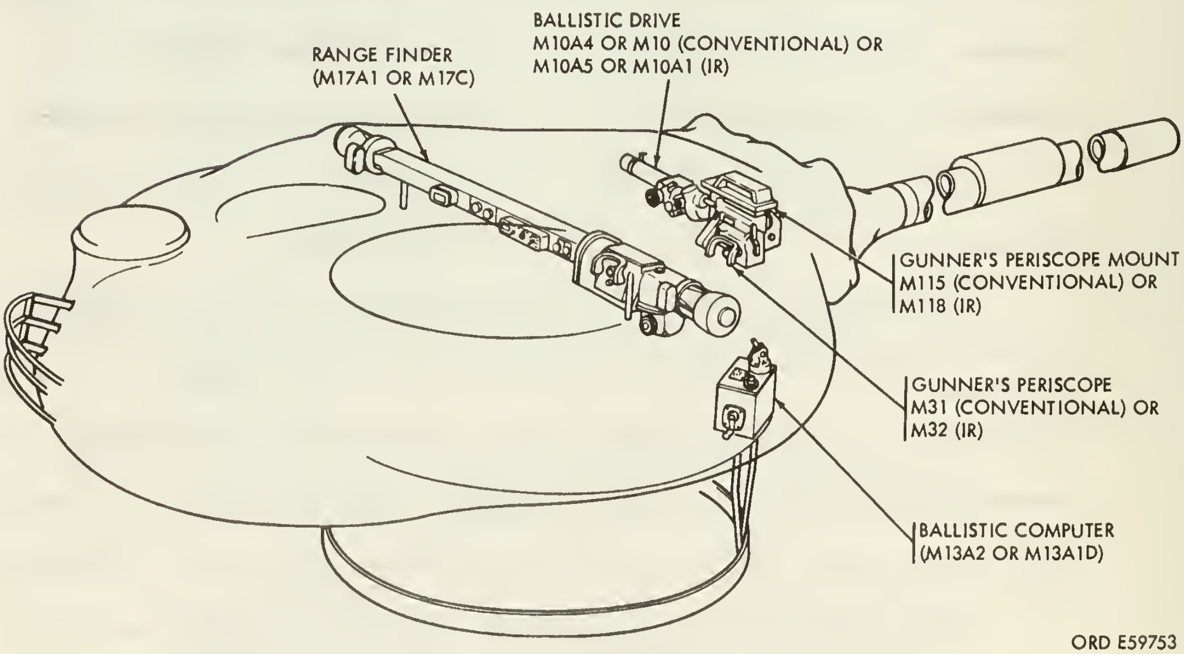
By applying the statistical tools listed in Appendix C we can estimate the parameters necessary to determine OHP by integrating over the entire target area presented. Also, with the statistics described, OHP may be readily extended to targets of somewhat different size and shape. Since the y and z components of the aiming error for any single round fired may be correlated, a test should be made during the data reduction phase to determine if the general bivariate normal distribution must be used with the appropriate numerical approximations to integrate over the exposed target area and yield OHP. (See Appendix C for further development of the integration techniques.)

Appendix D contains a discussion of the evaluation of $\hat{p}_{ijklmn}$ when the special case of no four, three or two factor interaction applies and we may accept the hypothesis (at the prescribed level of significance) that for one or more factors the level of a factor does not affect hit probability.

Experimentally determined OHP may be combined with mobility kill, firepower kill and total kill probabilities, which are available from the Army's Ballistic Research



TURRET COMPONENTS.



PRIMARY DIRECT SIGHTING AND FIRE CONTROL SYSTEM COMPONENTS.

FIGURE 3

Laboratories, to yield the unconditional probability of a kill by the following formula:

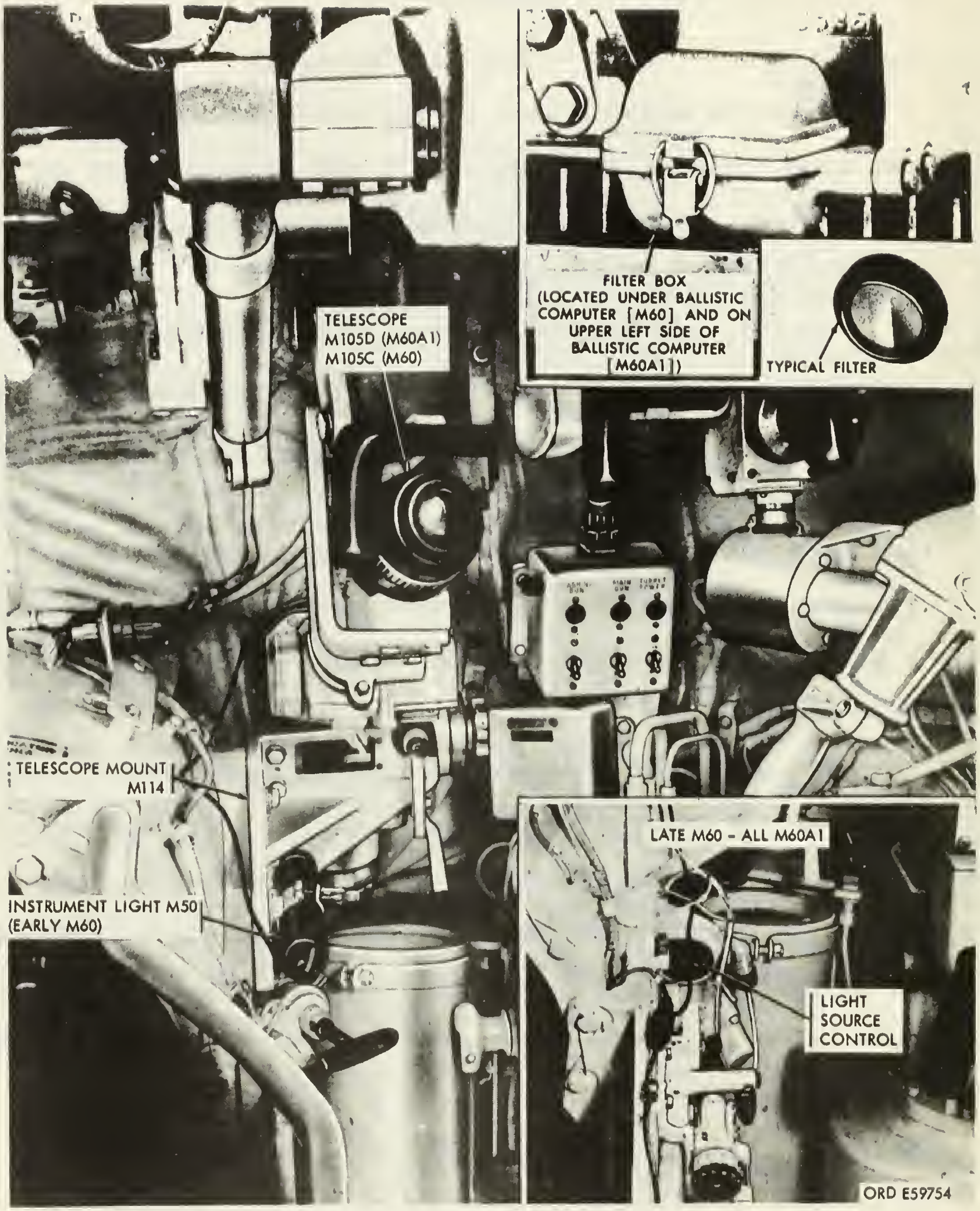
$$P_{KILL} = P_{HIT} \times P_{KILL/HIT}$$

With the machine guns we are concerned with both accuracy and area effects, i.e., do we hit the personnel and do the near misses lie within a designated suppressive fire distance?

Second, and equally important with accuracy, is the speed with which a tank crew engages a target and the rapidity with which successive rounds can be fired until destruction is achieved. Therefore time distributions for acquiring and detecting the target, time to open fire, and time to reload, relay and fire subsequent rounds and time to achieve a kill or a prescribed level of area coverage must be determined.

Third, and an offshoot of accuracy and speed of engagement, is the underkill, overkill problem. By determining the number of hits achieved after the computer declares target destruction, we will be able to comment on the degree of overkill. Underkill is defined to be failing to fire or continuing to fire on a target threat which is intervisible, a determination which the computer is also capable of making.

From these three categories of measurements we can answer the principal questions about OHP, but we can offer little in the way of insight into why crews did or did not achieve the level of hit probability we would expect for a



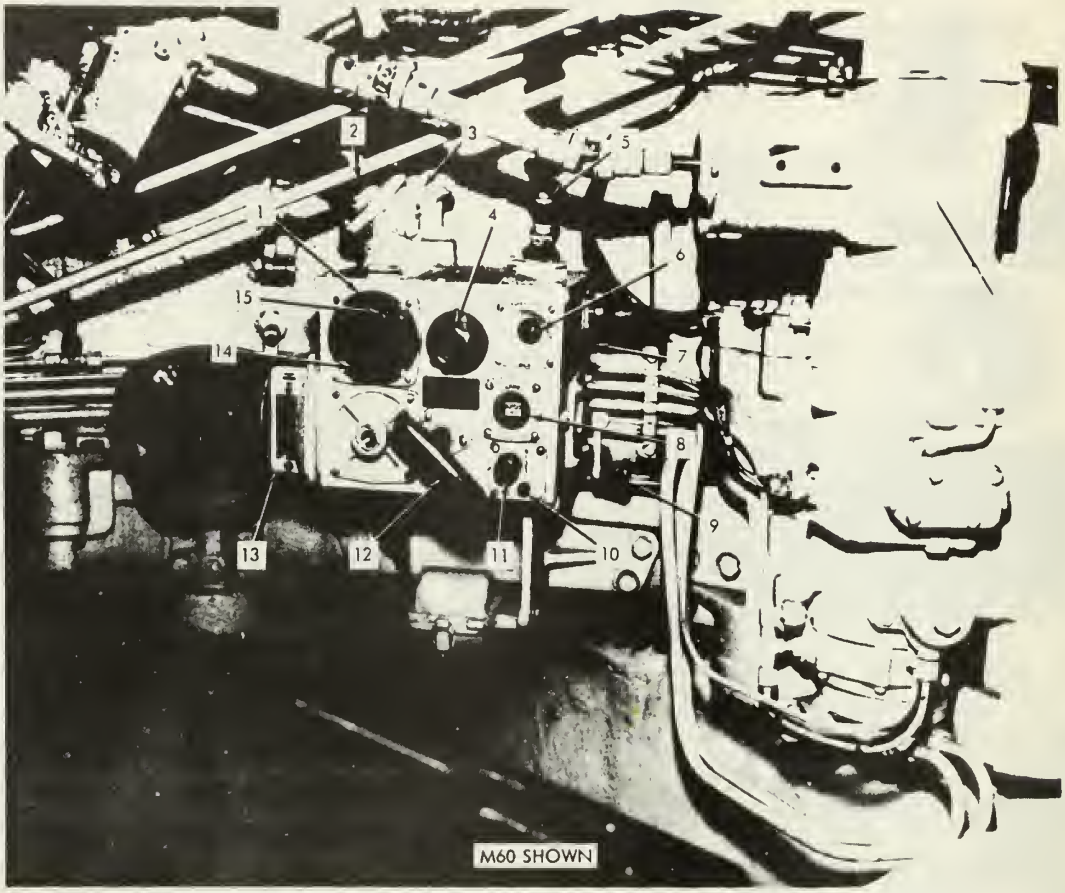
SECONDARY DIRECT SIGHTING AND FIRE CONTROL SYSTEM COMPONENTS.

FIGURE 4

given set of conditions. Although our experiment is capable of being repeated, expense may preclude any follow-on in the near future. Therefore it seems mandatory that a number of additional measurements be taken along with the primary ones in order that the data bank will contain sufficient information for the subsequent studies which are sure to follow this experiment.

The first item in this secondary set is a recording of the sight picture as seen by the gunner through his gunner's periscope. This recording will show what target was engaged and will show the dispersion of the aiming cross and lead lines for all rounds but the caliber..50, if the range and ammo used by the gunner is indexed into the tank fire control computer. Previous experimenters have used gun cameras split off the gunner's periscope to obtain the picture desired.

The second item is the range and ammunition indexed in the computer for rounds fired by the gunner. The HEP-T high explosive round would not be measured unless the range and HEP-T is indexed into the tank fire control computer while the gunner laid on the target with the articulated telescope. A camera mounted to take pictures of the face of the computer would record the amount of superelevation in the gun system at the time of firing which may be translated to range and compared with the gun to target range recorded by the external computer to determine the dispersion in range estimation.



1. RANGE SCALE.
2. SUPERELEVATION ACTUATOR SHAFT.
3. SUPERELEVATION OUTPUT SHAFT.
4. RANGE CORRECTION KNOB.
5. RANGE INPUT SHAFT.
6. SUPERELEVATION MIL COUNTER.
7. RHEOSTAT KNOB.
8. AMMUNITION INDICATOR.
9. SUPERELEVATION HAND CRANK.
10. RESET BUTTON.
11. RESET LIGHT INDICATOR.
12. AMMUNITION SELECTOR HANDLE.
13. CIRCUIT BREAKER.
14. OUTER (SUPERELEVATION) POINTER.
15. INNER (RANGE) POINTER.

ORD E59797

BALLISTIC COMPUTER (M13A2 OR M13A1D) CONTROLS.

FIGURE 5

Wind velocity and cant are two more important secondary factors. Each has an effect on the path which a round takes. Other items could be added to this secondary list. We would not increase the list, however, if in making the measurement we significantly detracted from the measurement of the primary areas of interest.

4. The Experiment and the Course Layouts

So far we have discussed in general the tactical situations, ranges, types of ammunition to be fired and the targets. Now we will discuss the experiment and course layouts which will lead to completing the description of the instrumentation felt necessary to gather data on the primary and secondary points being measured and then to describing how the data should be processed and tabulated for presentation.

To simulate the battlefield as closely as possible and apply psychological and physiological stresses to the experimental subjects, the experiment must fit into a tactical maneuver executed on a typical terrain such as is found at Ft. Irwin, California.

In general, each of the four tactical situations would be examined during the day, night and dawn or dusk. Dawn firing will be measured for one half the experimental units and dusk firing the other one half. All units would fire at night with one half the units using infrared illumination and the other half using howitzer fired flare type illumination and/or Xenon searchlight.

Let us next consider the number of experimental units (tanks and crews) needed for this experiment. The number of experimental units is a judgement factor. It is believed that 40 units grouped in the normal manner in eight platoons selected from four different battalions from at least three different major organizations (divisions, separate brigades or separate battalions) would provide a satisfactory sample size, since we want to observe at least 30 first round and 30 second round shots for each set of conditions. Platoon selection should be on a random basis.

Randomizing platoons versus type of combat should be accomplished to average out the learning effect from the type of combat and the four principal ranges and thereby better approximate the "average" platoon. For example, the eight platoons would be grouped into four groups lettered A-D and would be fired according to this (or a similar) randomized schedule.

TABLE II

Randomization of Platoon Groups

Legend: D = Day
N = Night
Dn = Dawn
Dk = Dusk

	ATTACK	MOVEMENT TO CONTACT	DEFENSE	DELAY
		1st Series		
A	3, D	4, D	1, D	2, D
B	4, D	1, N	2, D	3, N
C	2, N	3, D	4, N	1, D
D	1, N	2, N	3, N	4, N
		2nd Series		
D	3, D	4, D	1, D	2, D
C	4, D	1, N	2, D	3, N
B	2, N	3, D	4, N	1, D
A	1, N	2, N	3, N	4, N
		3rd Series		
C	3, Dn	4, Dn	1, Dn	2, Dn
D	4, Dn	1, Dk	2, Dn	3, Dk
A	2, Dk	3, Dn	4, Dk	1, Dn
B	1, Dk	2, Dk	3, Dk	4, Dk

Thus the group designated "D" would fire the attack course first at night. Group "C" would fire the attack course second at night. All ranges would be sampled during a platoon run. The first series for all groups would be fired before commencing the second series. At the end of the first series the sample proportion of hits for the attack and meeting engagement and defense and delay should be compared to test the hypothesis that for similar situations, light conditions, ranges, etc., the proportions may be presumed to be the same at the prescribed significance level. If the results of the tests indicate certain or all of the hypotheses may be accepted, the test director would consider omitting the respective meeting engagement or the delay from the second and third series and thereby reduce variable experimental costs and ammo costs.

Now let us consider a chronological description of experimental events as viewed from a test platoon's point of view. Within six months of the start of the experiment selected platoons would fire all gunnery tables at home station. (This is typical mobilization and deployment procedure for war time, the period we are simulating.)

Initially, upon arrival and after orientation in the test area, the platoon would commence two days of field maneuver. Then just preceding their first simulated combat situation the platoon would fire the tank crew qualification course with assigned vehicles after conducting boresighting and zeroing exercises. This would simulate previous combat experience or rehearsal by a new unit committed to combat.

These maneuvers would set the stage for measurement under average combat conditions and provide a build-up in the stress level.

Platoons would cycle throughout all 4 phases for day, night and limited visibility in approximately a 31 day period according to the following suggested schedule. (Additional free time should be added by the test director based on the situation.) Assume group C is conducting its first cycle; their activities would be programmed as follows.

TABLE III

Platoon Cycle for One Series

Day	1	Arrival, initial orientation, administrative inprocessing.
	2	Draw equipment, prepare to move to the field.
	3	Detailed orientation on experiment, prepare to move to the field.
	4-5	Two day non-firing platoon maneuver period including road marches, occupation of assembly areas, movement to attack positions, attack situations, occupation of defensive areas and execution of delay tactics.
	6-7	Maintenance of equipment and prepare to fire.
	8	Boresight and zero all weapons, correct weapon or sight malfunctions.
	9	Fire tank crew qualification courses, receive first operation order.
	10	Move to initial assembly area and commence 1st Series day delay and execute passage of lines.
	11	Reorganize, receive new operation order, move forward in preparation for night attack, execute night attack. Secure objective. Receive order to continue with day attack.
	12	Continue attack after dawn - this attack will be a meeting engagement. Receive order to execute defense.
	13	Continue occupation of defensive position, maintenance of equipment, execute night defense.
	14-15	Return to base camp, maintenance, prepare for next series.
	16	Receive order to move to the field, confirm zero.
	17-23	2nd Series, confirm zero during last day in preparation for 3rd Series.
	24-30	3rd Series
	31	Critique

We have previously discussed the target complexes in some detail; but, before discussing the attack, a few comments are appropriate. Targets must react on cue and give reaction signatures to firers who in turn respond as the situation dictates. This means the target must stop moving when a mobility kill is achieved, stop firing when a firepower kill is achieved, emit smoke to simulate a total kill when the tank is set afire, etc. The tank target should move from primary firing positions to alternate positions or at least give this impression to the attacking US platoon.

The target complexes to be engaged should be employed according to aggressor doctrine situations which will be described for each of the four tactical situations. A significant point to be observed is that in aggressor attacks, a numerical advantage of 5:1 to 7:1 is normal as compared to the typical US ratio of 3:1. Aggressor mass attacks were normal on the Eastern front in WWII and in Korea, and are normal today in Viet-Nam.

During any single engagement when the US platoon is attacking, a maximum of three targets would be exposed at a time. This number is considered to be the reasonable upper limit from the standpoint of our desired mass against the enemy. This number also tends to keep the level of load on the computer's real time target control subroutine and hit recording subroutine at an acceptable level. In the defense when the aggressor is attacking with a numerical superiority of say 5:1, the platoon's fire would be controlled by requiring the tanks to fire within specific subsectors.

Subsectors overlap somewhat but not to the extent all tanks fire at the same targets. (This is typical of unit SOP procedures in use today.) This technique simplifies the hit recording subroutine by limiting the tanks that could have fired a round at a target within a specific subsector.

In either the attack or the defense the computer solves the question of whether a round fired is a first, second or subsequent round by making use of the fact that there is a relatively low probability that more than one tank will fire its main gun at such a time that the rounds will arrive at the target area (attack) or target subsector (defense) within a very small increment of time on the order of five microseconds. Thus the computer solves the problem by first knowing where the targets are and gets an up to date sensing on where the US platoon is through signals from the direct range measuring system and second computing the time of flight for a round fired by eligible tanks and screening the list to see which one falls within the prescribed limits. It then checks its round counter subroutine for that tank, adds one more to the number fired and senses the location of the hit or miss which it stores in the appropriate location of memory for first, second and subsequent rounds. In theory this plan should work; however, a combination of gun camera recordings as well as film recordings taken through telescopes fixed behind the line of departure (or some other suitable location) will undoubtedly be required to back up the computer and solve those cases where the best the computer can do is designate which of several tanks could have fired a certain round. Then there would be the problem of manually determining which tank it was and feeding this data to the computer so that it could complete its hit and miss recording and print the results.

At this point we may combine all of the material previously discussed and describe the attack course which would typically be laid out as follows.

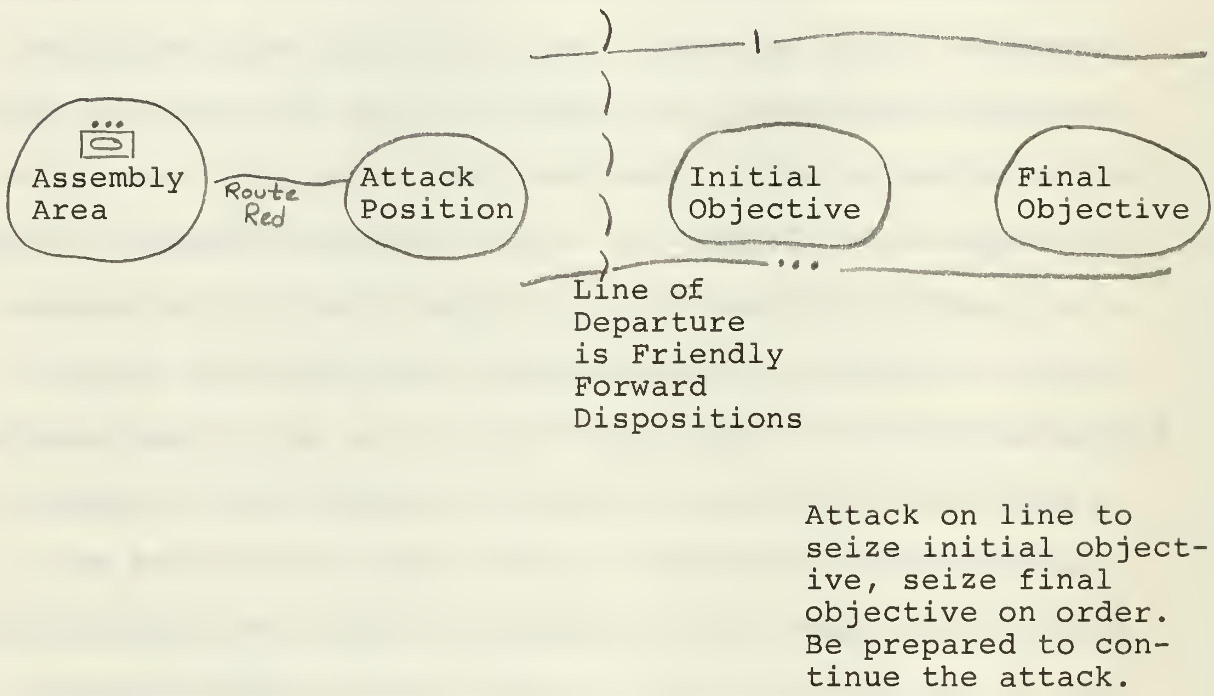
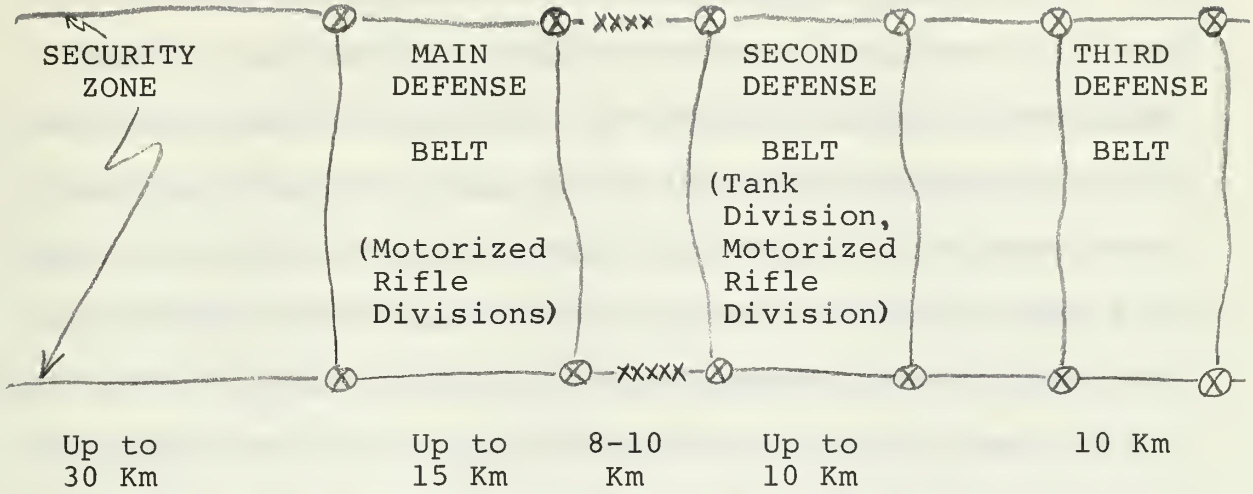


Figure 6

Our attack implies aggressor defense which is typically laid out in depth with the following dimensions.[1]

[1]FM 30-102. Handbook on Aggressor Military Forces (Department of the Army, January 1963), p. 97.



AGGRESSOR DEFENSE

Figure 7

The principal segment of the belt pattern is the main defense belt manned by motorized rifle divisions; therefore, we will assume that elements of this type division constitute the normal aggressor defensive force for our experiment.

Within the main defense belts aggressor motorized rifle battalions organize three lines. A cross section would show two platoons of a company in the first defense line and the third platoon in the second. Second echelon companies place all three platoons abreast in the third defense line. A platoon of two antitank guns or recoilless rifles and a platoon of three tanks is normally attached to the first line companies.[1] Organic weapons include rifles, automatic

[1]FM 30-102. Handbook on Aggressor Military Forces (Department of the Army, January 1963), pp. 105-107.

weapons and rocket launchers.

The overall appearance to the attacking force would be one of a series of defensive positions organized in depth which would appear randomly to the right and left front and center of the direction of the attack. In the instrumentation section we will discuss how targets will be positioned and operated; at this time we will assume they would appear at random ranges but generally at greater ranges at the start of the exercise with range decreasing as that exercise progresses. The relative range between the firing platoon and target would be kept within a 200 meter bracket for a particular engagement principally by the computer's target control program. However, the test director's staff, acting as the company headquarters, may have to impose restrictions on the spot to prevent the test platoon from simply charging the objective at top speed without stopping to fire the main gun. After the platoon passes through the 600 meter bracket, it is expected that the platoon will close rapidly on the objective using machine gun fire to kill or suppress the enemy. Prior to reaching this bracket, the test platoon should use its band of maneuver room to advantage to include such techniques as firing from a primary position and then moving to an alternate one to continue firing. It is expected the main gun engagement at the 600 meter bracket would be relatively brief.

The US attack is characterized by as much detailed planning and reconnaissance as time and the situation permit. It differs principally from the meeting engagement in this respect. Supporting weapons, including artillery, mortars and tactical air are employed to soften up the enemy. (These supporting weapons are simulated in our experiment.) Intelligence agencies attempt to locate aggressor positions and identify their activity. The night attack may be contrasted with the day attack in terms of the depth of the objective. At night the objective is more limited and the attack is more deliberate in execution due to the somewhat restricted visibility.

Now let us take a look at what a typical platoon would experience in the day attack and then point out any differences peculiar to the night and the limited visibility attacks.

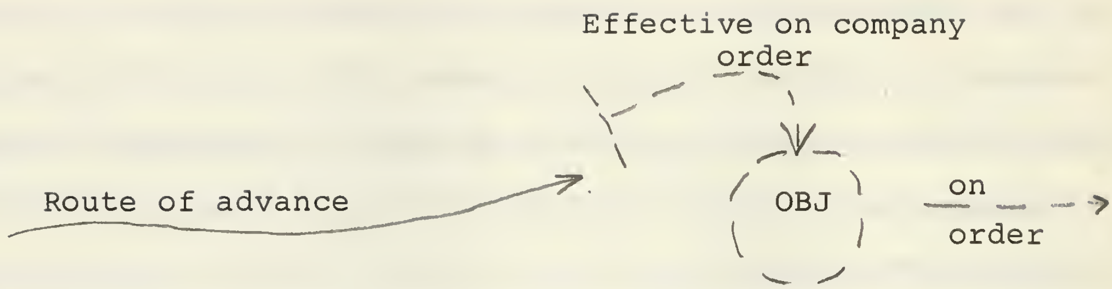
At some time, perhaps 12 to 24 hours prior to the attack, the test director's staff acting as the company commander, would issue a warning order to the platoon that a move would be made to a forward assembly area in preparation for an attack which is expected to be launched at h-hour on d-day through friendly front lines. Operations orders would follow, the move would be made, final preparations and reconnaissance would be completed. In the assembly area the acting company commander would issue the attack order which would require the test platoon to seize two objectives during the day and be prepared to continue to the third. During the night attack the test platoon would be ordered to seize one objective and be prepared to continue the attack at first light. The limited visibility attacks would be quite similar. With the dawn attack, the test platoon would move forward to the line of departure under the last moments of darkness and commence the attack in semi-darkness which would turn to day by the time it reached the first objective. Thereafter the pattern would be the same as the day attack. The dusk attack would commence as the light begins to fade and would be a night attack by the time the test platoon reaches the first objective, which may be located somewhat deeper into enemy terrain than the strictly night attack. As in the night attack, the test platoon would be prepared to continue the attack at first light. Although the experimental course would not include measurements for the be prepared phase, it would be good training to occasionally order the platoon to begin the execution of the be prepared mission to keep them on their toes.

In all attacks, typical radio traffic with the simulated company headquarters and the artillery forward observer would be conducted as part of the stress environment.

During the attack targets would initiate cues and give reaction signatures to firers who would in turn respond as the situation dictated. This means the target must stop moving when a mobility kill is achieved, stop firing when a firepower kill is achieved, emit smoke to simulate a total kill when the target tank is set afire, etc., as we have discussed.

Now we have considered the attack phase in some detail. We can move to the meeting engagement and discuss it by way of contrast with the attack. The first point which should be made is that the meeting engagement should be tested over different terrain than the attack to prevent contamination of the data obtained. Because the stress environment is so important to the outcome of the experiment, we should vary the test course between the attack and meeting engagement enough to ensure that they do not have a detailed first hand knowledge of the terrain.

After the platoon is issued a warning order followed by an operation order, the meeting engagement should commence with the test platoon in march column acting as an advance guard for a larger force which is following as the main body. Aggressor would be deployed in depth as in the attack and would consist of the standard test targets already described. When the engagement is commenced the test platoon should be ordered to maneuver to one flank or the other and commence their attack. (Which flank would be assigned to which platoon would be randomly selected but would be equally divided and whichever flank is assigned should coincide with the tactical situation so that it is a logical course of action). The test platoon must develop its plan of attack rapidly and commence the attack. After it overran the opposition, it would be ordered to reform and continue its advance guard mission. The night meeting engagement would be virtually the same as the day situation just described except one half of the units would employ infra-red searchlight to provide illumination, while the other half used Xenon searchlight and/or howitzer fired illuminating rounds.



Surprise targets appear vicinity of objective. Dashed lines show orders to be issued by company commander.

MEETING ENGAGEMENT

Figure 8

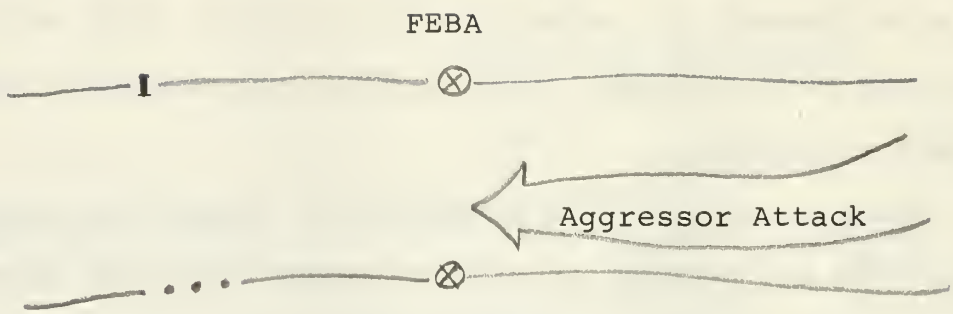
The defense is characterized by deliberately prepared positions and a mission to hold certain key terrain. The test platoon would be permitted time to carefully reconnoiter their area of responsibility and prepare firing positions and range cards. Therefore, it is not felt necessary that the day and night defense be run on different terrain. The manner in which the targets would be presented would be changed between the day and night tests. Since aggressor would be attacking, tanks and armored personnel carriers would be appropriate targets. Aggressor normally stays mounted in their carriers until the last possible moment at which time they dismount and continue the attack on foot. At this time pop-up targets would simulate the dismounted infantry.

Relative motion with the dismounted infantry targets may be achieved through the target control program which would cause the more distant targets to drop and somewhat nearer targets to appear.

The platoon would be permitted to engage the enemy during the day defense at greater range than 2000 meters if terrain and visibility permit and the tank gunnery qualification course firing shows it would be profitable to add another sample range of about 2400 meters.

We have already observed that aggressor would attack in mass with an advantage of some 5 or 6:1. Our tanks will engage targets appearing in their subsector. The first time the targets appear they would be within a 200 meter firing bracket; therefore, intervisibility equals threat and starts the time distribution clocks. Aggressor would take maximum advantage of the terrain. If our gunners kill all of the targets in a subsector, the computer would override its normal program and cause at least one remaining target in each subsector to advance so that we can sample at each range. The statistical control would require the platoon to fire only in prescribed range brackets.

The night and limited visibility defense test would use the same proportions of IR, Xenon searchlight and howitzer fired illuminating rounds as in the attack.



THE DEFENSE

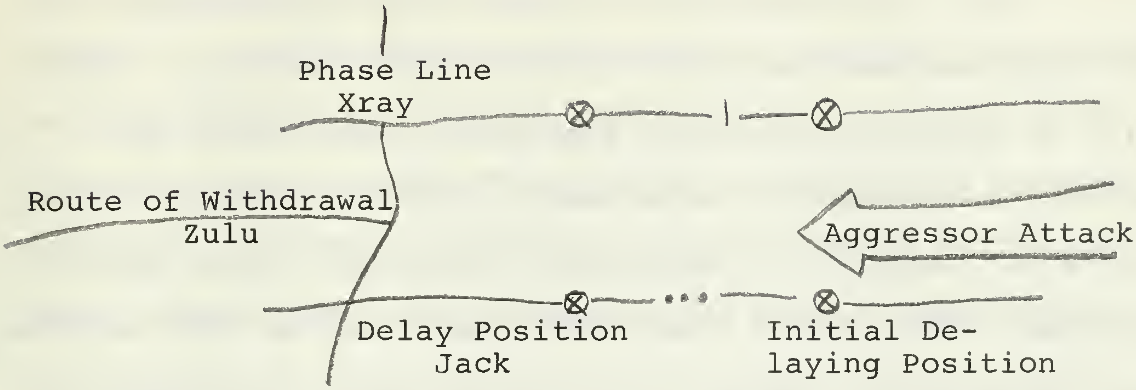
Figure 9

The delay is similar in many respects to the defense except the unit executing the delay does not intend to hold key terrain at all costs, but rather trade space for time. Until the time comes to withdraw before becoming decisively engaged, the techniques employed in the delay at platoon level parallel the defense.

In our experiment we would require the test platoon to occupy two delaying positions and then make a passage back through friendly lines. As in the defense the platoon would be permitted to engage during the day delay at longer range if the conditions described are met.

Because we do not desire the test platoon to become decisively engaged, only tank and armored personnel carrier targets should be required.

The night and limited visibility delay would be executed with the same proportion of IR, Xenon searchlight and/or howitzer fired illuminating rounds as in the attack. It is expected that the maximum range at which the test platoon can first effectively engage the targets at night or limited visibility will be somewhat less than the day delay.



THE DELAY

Figure 10

5. Instrumentation

The instrumentation to gather time distribution and hit data has been described in some detail already. Basically an array of electronic equipment notes events and signals a high speed, large memory capacity, digital computer which records all events and drives the target control program. It is hoped that little data must be hand recorded and fed into the computer but that automatic recorders can handle the entire task except checking tank like targets to ensure they were engaged only by main gun ammo. A few more comments are in order to complete our discussion of instrumentation.

In the target identification phase very, very high frequency (line of sight) transmitter and receiver combinations mounted on target and firing tanks respectively will note and relay to the computer the time when intervisibility exists. Targets will not be made intervisible unless they are capable of being a threat; thus, the time of intervisibility equals the time of initial threat.

It will be necessary to place an electronic switch in the tank by the commander and each member of the crew to provide the impulse to record when the tank commander or a crew member first detects and subsequently identifies a potential target, as no mechanical mechanism on the tank moves at this time which could trip a switch.

The target complexes have been described in detail. The tank or tank size targets should be capable of movement and must record rather precisely the point at which a round hits or misses the vehicle in relation to some known reference point on the vehicle. The sensing array should be capable of making accurate sensings for tracks perpendicular, parallel and at a 45 degree angle to the gun target line. Targets would not take more than one track during any one tactical situation; therefore, the array could be set before a test began and would not have to be changed during a run.

Due to the arch effect in the HEP-T trajectory the aiming error can be better measured by using seismic devices to sense the location of the detonation which will permit us to obtain the aiming error statistics desired described in the vertical plane.

The target control program should be set to randomize the appearance of targets and should present roughly an equal number to the test platoon's right and left front and center. Although the location where a set of targets appears to the test platoon varies, the set should include the same number of targets for each range situation for each platoon to provide an underlying basis for statistical comparison.

The number of targets is somewhat a random variable. In the defense and delay there was little problem because the targets start at the far range bracket and continue to move forward by bounds. The number is fixed after the test director decides on aggressor's numerical advantage. The attack is a different problem. The requirement is to place out enough targets so that we get at least 30 first round trials and 30 second round trials for each situation. Until the ammo limitation is set and the cost of instrumentation is fixed, it is difficult to be more specific than to say we want aggressor to have a defense in depth.

We have previously discussed the fact that the principal gun camera "sees" the same thing the gunner does through his periscope. The cal..50 poses a particular problem in that the TC cupola is free swinging with respect to the turret and hence the gunner's gun camera; therefore an additional camera must be mounted coaxially with the cal..50 to determine what target was engaged and what general aiming point was selected from observing the tracers.

A round counter circuit must be installed on each weapon on each vehicle to signal the computer when that gun fires.

And finally, we will want to record the interphone conversation in each tank to back up the detection and identification sensings, and the radio traffic on the platoon and company command nets.

6. Presentation of the Data

After the data has been analyzed and reduced, results should be tabled in a looseleaf handbook for the 105 mm gun tank. In general, the initial section of the handbook should list technical performance data which has already been developed by the Army's Ballistic Research Laboratories at Aberdeen Proving Grounds. The second section should contain the OHP data listed by type of combat, caliber of weapon, ammo, state of target movement, range, visibility and round sequence. Within each subsection identified by type of combat through visibility, we would place (1) the distribution of time from first intervisibility to detection, (2) the distribution of time from detection to identification (when this can be determined), (3) the distribution of time from identification to first engagement (in the defense this applies to the far range bracket only and in the offense, defense or delay this applies only when the target is within a range firing bracket at the time of identification), (4) the distribution of time to fire the second, third and successive rounds (main gun only), (5) the distribution of time during which suppressive machine gun fire was placed in the target area and the percentage of the area covered by this fire, and (6) the average speed at which the platoon is able to close on the objective in the case of offensive maneuvers.

The hit or effects data presented in the OHP section in this proposal is confined to only two types of main gun rounds and two types of machine gun rounds. (However, the looseleaf feature allows the addition of follow-on results, should the full blown program be ordered executed.) HEAT and HEP were selected because they present two different problems in target sensing and presentation of the data. We have discussed how OHP would be obtained for HEAT ammunition. Using this method we can describe confidence intervals on the hit and kill probabilities. HEP is an explosive round and as such achieves an expected fraction of casualties for a certain density of personnel and their posture. Therefore, it will be necessary to combine the dispersion of the aiming error, gun-target range and the angle of impact with data available at BRL to develop confidence intervals on the expected fraction of casualties based on normal aggressor weapons employment and density of troops.

If the pulse doppler radar devices currently under development are available in quantity during the time of this experiment, we will be able to identify the targets hit by maching gun fire and thereby estimate the fractional coverage by "X" number of rounds fired when all of the previously mentioned conditions have been fixed. It may be necessary to settle for less precise methods. An alternative method would be to compare the HEP expected fraction of casualties with the number of hits obtained on the silhouette targets and arrive at the machine gun hits by approximating the difference. (To say the least, accurate evaluation of machine gun fire in this experiment may require further instrumentation development and assessment techniques before it can be accurately sorted out from high explosive effects.)

Within each section of type of combat through target movement we should describe the degree of underkill or overkill if it existed. In effect we are describing the degradation factor, if any, that comes as a result of massing firepower in a stress situation.

The final section should contain the product of the conditional kill data (listed as part of the technical performance data) and the OHP data to give a section called the unconditional kill section. This final section should contain the same breakout for subsections as were made in the OHP section with the additional feature of listing kills by type, i.e., mobility, firepower and total. The time distributions described for the OHP section would not be repeated. An additional distribution would be included; the distribution of time from first engagement until a kill was achieved or the target was rendered ineffective.

We have provided researchers, planners and war gamers with time distributions, hit and kill data derived from observing a 105 mm gun tank platoon operating in a simulated combat environment. We have included the theoretical data for the tank which has been developed by BRL. Thus we feel we have combined all of the knowledge and empirical observation available on this weapons system into one package for ease of use in making cost effectiveness studies, conducting war games using such devices as Carmonette (RAC)[17] or Dyntacs (Ohio State University) [3], or a whole host of uses.

7. Costs

In analyzing the costs we should consider sunk, variable and fixed (or mixed) costs that would be chargeable to the agency conducting the experiment and consider separately the additional costs which the decision maker must consider when he evaluates the overall cost of obtaining OHP for the M-60 tank system.

In the sunk category goes the cost of the computer. This item will be purchased for general use and will have already been paid for by the time frame assumed in this paper. It is anticipated the computer will have excess capacity; therefore, opportunity costs are assumed to be zero. Likewise the firing range and post facilities have already been paid and are therefore sunk costs.

The variable costs are ammo; the operation and maintenance of vehicles, weapons and instrumented target systems; personnel pay and allowances less travel pay; POL; and data processing and editing and publication of the looseleaf handbook. Each of these costs varies as a function of the length of the experiment or the number of platoon experimental runs.

Relatively fixed (or we might say mixed) costs which do not depend on the length or number of runs in the experiment are personnel travel pay; equipment transportation costs; and the cost of developing and fabricating the instrumentation. From the last cost must be subtracted the expected future value to other experiments.

Each of the above costs is relatively easy to compute when the final experimental plan is prepared and negotiations are completed with Continental Army Command for the specific troops and test facility which they must provide. Total cost is a summation of the variable and fixed costs.

Further definition of specific costs is therefore deferred to the completion of the final experimental plan.

As mentioned earlier in this paper, ammunition costs do not bear directly on the agency conducting the experiment; however, the opportunity costs for the ammunition, which we assumed to be the replacement cost for new rounds, should be added to the aforementioned experimental cost to yield the grand total price tag for obtaining M-60 tank system OHP. Because tank systems are quite similar in design, one may easily infer (with some minor substitutions for such things as the difference in cost of ammunition) what it would cost to evaluate the M-48, the predecessor of the M-60, or the MBT-70, the tank system under design at this time as the follow-on to the M-60.

8. Conclusions

This thesis has presented a methodology for obtaining operational hit probability and unconditional kill given hit data. The test subjects required, the courses to be run, the measurements to be taken, the sensors required and the costs involved were described. It is felt that this experimental course or one similar will adequately measure OHP on any terrain where M-60 tanks (or other models) would be employed. The types of rounds of ammunition could be readily expanded and more range measurements could be taken, as the program budget permits. An underlying assumption is that the instrumentation is semi-portable and will permit a "change of scenery" without great difficulty.

By sacrificing some of the realism it is believed this test program could be fielded with the current inventory of instrumentation if antitank rounds can be sensed for location of hits and misses.

Costs are readily identifiable; therefore, the results of the experiment should provide the decision maker with a cost-benefit analysis upon which to decide the future of the OHP program.

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APPENDIX A

The computation of an estimated number of trials for each set of conditions, in particular range, may be readily evaluated by using the following relationships where:

S_n = the number of successes in n independent Bernoulli trials.

p = the probability of success on each trial.

q = 1-p = the probability of failure on each trial.

α = the lower bound on the probability of observing p to within some arbitrary difference.

ε = the arbitrary difference in absolute value.

$F_n = \frac{S_n}{n}$ = the relative frequency of success,[1]

Φ, ϕ = standard normal distribution, density functions respectively.

$$P[|S_n - np|/\sqrt{npq} \leqq h] = 2\Phi(h) - 1$$

or

$$P[|f_n - p| \leqq \varepsilon] \doteq 2\Phi(\varepsilon\sqrt{n/pq}) - 1$$

Now define $K(\alpha)$ as the solution to the equation

$$2\Phi(K(\alpha)) - 1 = \int_{-K(\alpha)}^{K(\alpha)} \phi(y)\,dy = \alpha$$

where

α	$K(\alpha)$
0.50	0.675
0.6827	1.000
0.90	1.645
0.95	1.960
0.9546	2.000
0.99	2.576
0.9973	3.000

we find $n \geqq K^2(\alpha)/4\varepsilon^2$

[1]E. Parzen, Modern Probability Theory and its Applications, (New York: John Wiley and Sons, Inc., 1965), pp. 231-2.

Assuming that 90% of the time we desire to estimate p to within .15 of its actual value, we obtain

$$n \geqq \frac{(1.645)^2}{4(.15)^2} \doteq 30$$

The procedure is identical for computing the hit probability for the defense and the delay.

If p is either greater than about .8 or less than about .2, which may occur at short or very long ranges respectively, the normal approximation is not very accurate for estimating n. An alternative approach would be the Poisson approximation to the binomial to estimate the number of trials required.

It is noted that in this argument the underlying distribution is binomial, whereas in actually obtaining an estimate of a particular p from observing the outcomes of tank firings, we will use the normal distribution and integrate over the target area. The assumption made is that the number of rounds required to obtain an estimate of p in the case of sampling from a binomial distribution is sufficiently close to the number required to get the same degree of accuracy in the case of estimating a bivariate normal distribution, and then integrating the sampled distribution.

If the recommendation of eight platoons (of five tanks each) is approved, we can expect to have 40 or more rounds fired at each data coordinate which is 33-1/3% more than the desired minimum determined by the above model.

APPENDIX B

During the experiment after half of the firing platoons have completed the four simulated combat courses the test director should have a statistical comparison made between the estimated probability of hit for the attack and the meeting engagement and similarly between the defense and the delay to test the hypothesis that in each case the probability of hit is the same for a particular range, type of ammunition, round sequence number, state of target movement and visibility condition. Thus in the case of the attack and the meeting engagement, we would perform the following analysis for first and also second rounds assuming the number of trials is respectively sufficiently large and therefore the difference in the two sample proportions will be approximately normally distributed. The $\hat{p}$'s are determined by integration techniques outlined in Appendix C.

Definitions. (1) $\hat{p}_a$ = estimated probability of a hit in the attack for a specific range, type of ammo, round sequence number, state of target movement and visibility condition.

(2) $\hat{p}_m$ = estimated probability of a hit in the meeting engagement - same conditions as noted in (1) above.

(3) n_1 = rounds fired in the attack, conditions as noted in (1) above.

(4) n_2 = rounds fired in the meeting engagement, conditions as noted in (1) above.

H_0: $p_a = p_m$, H_a: $p_a \neq p_m$

therefore $\mu_{\hat{p}_a - \hat{p}_m} = 0$.

Define $\hat{p} = (n_1\hat{p}_a + n_2\hat{p}_m)/(n_1 + n_2)$

then

$$\sigma_{\hat{p}_a - \hat{p}_m} = \sqrt{\hat{p}(1-\hat{p})/n_1 + \hat{p}(1-\hat{p})/n_2}$$

$$= \sqrt{\hat{p}(1-\hat{p})(n_1+n_2)/(n_1 n_2)}$$

The recommended decision rule is that if for our assumed significance level of .10

$$|\hat{p}_a - \hat{p}_m| < 1.645\sigma_{\hat{p}_a - \hat{p}_m}$$

holds for both first and second rounds, respectively, we would accept the hypothesis that the probability of a hit for attack and meeting engagement (under similar conditions) are equal and discontinue further testing of the meeting engagement for that set of conditions.

The procedure for comparing the defense and the delay is the same.

APPENDIX C

From the sample data the operational standard deviations, the components of which are assumed to be normally distributed, and correlation coefficients of aiming error may be estimated by the following formulas. If we assume the main gun was boresighted and zeroed according to accepted doctrine then the expected strike of a round is the aiming point. We will arbitrarily designate the center of the y-z plane as the center of the mass. Then we may compute the following statistics with regard to the specified reference point. The multivariate normal distribution will be centered at $\overline{Y}$ and $\overline{Z}$ as measured from the reference point. Thus we estimate

$$\hat{\sigma}_y^2 = \frac{1}{n} \sum_{i=1}^{n} (y_i - \overline{y})^2$$

Where n - number of rounds fired for a particular situation and range

y_i = distance in the "y" direction from the reference point to the point in the y-z plane where the round passed through the plane.

$\overline{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$ = defined similarly to $\overline{z}$ below

In like manner we may compute

$$\hat{\sigma}_z^2 = \frac{1}{n} \sum_{i=1}^{n} (z_i - \overline{z})^2$$

Where n = as before

z_i = distance in the "z" direction from the reference point to the point in the y-z plane where the round passed through the plane.

$\bar{z} = \frac{1}{n} \sum_{i=1}^{n} z_i$ = distance in the "z" direction from the reference point to where the average of all n rounds passed through the plane.

From the above we may obtain

$$\hat{\sigma}_y = \sqrt{\hat{\sigma}_y^2} \qquad \text{and} \qquad \hat{\sigma}_z = \sqrt{\hat{\sigma}_z^2}$$

Using the same data we may estimate the correlation coefficient, $\hat{\rho}$, which is a measure of the interrelationship between y and z components of an individual round fired. (Note $\hat{\rho}$ does not measure any interrelationship between two different rounds, in fact it assumes independence. $\hat{\rho}$ is defined as

$$\hat{\rho} = \frac{1}{n\hat{\sigma}_y\hat{\sigma}_z} \sum_{i=1}^{n} y_i - \bar{y}) \; (z_i - \bar{z})$$

$\hat{\rho}$ may take on values such that $0<|\hat{\rho}|<1$. Small absolute values of $\hat{\rho}$, e.g., $|\hat{\rho}|<.2$, tend to indicate independence of the y and z values for a given round; whereas, large absolute values, e.g., $|\hat{\rho}|>.8$ tend to indicate dependence of the y and z values.

A test of the hypothesis, Ho, that y and z values of an individual round are independent would be performed as follows.

We calculate $\hat{t} = \hat{\rho}\sqrt{n-2}/\sqrt{1-\hat{\rho}^2}$

From a "Student's" t table we look up the value for $t_{(1-\alpha/2, n-2)}$ where α is the level of significance. (α = .10 is recommended.)

If $|\hat{t}$ calculated$| < t_{(1-\alpha/2,n-2)}$ we accept the hypothesis y and z are independent for an individual round; otherwise we reject H_o.

If the result of the correlation test is to accept H_o the total OHP for a given situation and range may be computed by integrating using the following formula.

$$\hat{p} = \int_{\substack{\text{Area of} \\ \text{the target}}} \frac{1}{2\pi\hat{\sigma}_y\hat{\sigma}_z} \exp\{-\tfrac{1}{2}[(y-\bar{y})^2/\hat{\sigma}_y^2+(z-\bar{z})^2/\hat{\sigma}_z^2]\}$$

If we break up the target into rectangles and express y and z in standard form, we may refer to a standard normal table and readily compute the probability associated with a respective rectangle and then sum the rectangles.

If we reject H_o the total OHP for a given situation may be computed using the following method.

The general procedure is adapted from reference [1], Appendix D.3, which describes a computer program for the IBM 7094 using FAP language and was written by Mr. Richard Freedman. The program computes about 70 points per second and has six-deciman accuracy.

The procedure is to make a substitution for the general bivariate normal distribution f(y', z') by substituting our estimated parameters

$$y = (y'-\hat{\mu}_Y)/\hat{\sigma}_Y \qquad\qquad z = (z'-\hat{\mu}_Z)/\hat{\sigma}_Z$$

to give a bivariate normal distribution with zero means, unit variances and correlation coefficient $\hat{\rho}$. We now have

$$f(y,z) = \frac{1}{2\pi(1-\hat{\rho}^2)^{1/2}}\exp\{-\frac{1}{2(1-\hat{\rho}^2)}[y^2-2\hat{\rho}yz+z^2]\}$$

Let

$$k^{-1} = 2\pi\sqrt{1-\rho^2}$$

then

$$f(y,z) = k \exp\left\{-\frac{1}{2(1-\hat{\rho}^2)}[(y-\hat{\rho}z)^2+z^2(1-\hat{\rho}^2)]\right\}$$

or

$$f(y,z) = k \exp(-z^2/2) \exp\left[-\frac{(y-\hat{\rho}z)^2}{2(1-\hat{\rho}^2)}\right]$$

then

$$P\{a<y<b,\ c<z<d\} = k\int_c^d \exp(-z^2/2)\left[\int_a^b \exp\left(-\frac{(y-\hat{\rho}z)^2}{2(1-\hat{\rho}^2)}\right)dy\right]dz$$

$$= \frac{1}{2\pi}\int_c^d \exp(-z^2/2)\left[\int_{\frac{a-\hat{\rho}z}{(1-\hat{\rho}^2)^{1/2}}}^{\frac{b-\hat{\rho}z}{(1-\hat{\rho}^2)^{1/2}}} \exp(-y^2/2)dy\right]dz$$

$$= \frac{1}{(2\pi)^{1/2}}\int_c^d \exp(-z^2/2)\left[G\left(\frac{b-\hat{\rho}z}{(1-\hat{\rho}^2)^{1/2}}\right) - G\left(\frac{a-\hat{\rho}z}{(1-\hat{\rho}^2)^{1/2}}\right)\right]$$

Where

$$G(Y) = \int_{-\infty}^{Y}(1/\sqrt{2\pi}) \exp(-t^2/2)dt$$

Mr. Freedman's program uses the above simplification and Hasting's approximately to evaluate G.

A helpful expression to be used in evaluation G(y) is

$$G(y) = \begin{cases} \frac{1}{2} + \frac{1}{2}\Phi(y/\sqrt{2}) & \text{if } y > 0 \\ \frac{1}{2} - \frac{1}{2}\Phi(-y/\sqrt{2}) & \text{if } y \leqq 0 \end{cases}$$

where

$$\Phi(t) = 1 - (1 + 0.278393t + 0.230389t^2 + 0.000972t^3 + 0.078108t^4)^{-4}$$

This procedure evaluates the probability of a hit in a rectangle. To evaluate $\hat{p}$ for a particular target we would break up the target into a number of rectangles, calculate the probability of hitting each rectangle and sum over all the rectangles.

Thus, for n rectangles

$$\hat{p} = \sum_{i=1}^{n} \hat{p}_i$$

where $\hat{p}_i$ is calculated by substituting the appropriate limits for a, b, c and d.

APPENDIX D

Although it is suggested there may be an interaction between range, visibility, the sequence number of the round and the state of target movement, it is quite reasonable to expect there is no four or three factor interaction. It may well be that a test will show there is no two factor interaction when we look at the estimated hit probabilities.

If this is the case we should further test within the two basic types of main gun rounds, antitank and anti-personnel, to determine if the level of any one (or more) of the five remaining factors has no effect on hit probability. For each factor for which we may accept the hypothesis that its main effect is zero, we would average hit probability over that factor and thereby improve our estimate of p due to increased sample size.

A general discussion of the N-way classification with interaction and the appropriate analysis of variance may be found in An Introduction to Linear Statistical Models, Volume I, McGraw-Hill, 1961, by F. A. Graybill on pp. 272-279.

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13. ABSTRACT

The Department of the Army has requested the U.S. Army Combat Developments Command develop a methodology for determining operational hit probabilities for three pilot man-weapons systems, one of which is the M-60 tank, where the operating personnel are subjected to the psychological and physiological stresses of the simulated combat environment. This thesis describes a proposed experimental methodology applicable to the time frame FY 1969 and beyond for obtaining hit probabilities to include the preliminary experimental unit firing exercises and method of selection, the courses to be fired, the instrumentation requirements, several statistical techniques to be used in data reduction, a format for presenting the resulting data and the cost involved in the experiment.

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